Free Molecular Flow In The Holweck Pump

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Abstract. The numerical algorithm for simulation the free molecular flow in the Holweck pump based on test particle Monte Carlo method is developed. The results obtained by this method for real cylindrical geometry of the pump taking into account the rotation of the rotor with multi-grooved channels are in good agreement with measured results [1] for low-pressure conditions. The critical analysis of the model, proposed in Ref. [1] for the flow in the pump that is based on the plane representation of the pump geometry, is made.

INTRODUCTION

The Holweck type pump represents one of the versions of a molecular pump where a drag of molecules is carried out by a moving surface [2]. In modern versions of Holweck pump the spiral grooves are placed on the rotor instead of external cylinder. This screw-grooved pump is widely used as an outlet stage of turbomolecular pump [1].

The flow in the Holweck pump is of complex structure due to its three-dimensional character and the effect of leakage from high-pressure side to low-pressure one caused by the clearance between the rotor and the external cylinder. An approximate model for the flow in the pump is proposed by Tatsuo Kanki [1]. This model is based on the solution of model Boltzmann equation for a two-dimensional flow in a rectangular channel with a moving plate and subsequent applying this solution to one-dimensional gas flow along the channel of the pump. The results obtained by this model are in good agreement with the experiment [1].

For low-pressure operation conditions, when the effect of molecular collisions is small, the flow in the Holweck pump as well as its pumping characteristics may be exactly predicted by test particle Monte Carlo method. The results obtained by this method for real cylindrical geometry of the pump taking into account the rotation of the rotor with multi-grooved channels may be used to check the accuracy of Kanki's approximate model in the free molecular limit.

PROBLEM FORMULATION

Free molecular flow in the Holweck pump was simulated by well known test particle Monte Carlo method. The pumping process in the considered case is completely characterized by two values of direct (K_1) and back (K_2) transmission probabilities. The main problem to be solved during the simulation of molecule motion in the pump tract is to find the point of intersection of their trajectory, which represents a straight line, with the surface of the tract. The latter may be either at rest (external cylinder) or moving (rotor with grooves and vanes). On the back boundaries of the channel formed by the groove and the vane the symmetry conditions are used, i. e. the molecule leaving the channel from one side is returned into the channel from another one with the same values of radial, angular and axial components of their velocities. On solid surfaces the diffuse-specular reflection of molecule with some accommodation coefficient σ is assumed.

The simulations were performed for the geometry of the pump used in [1] for theoretical and experimental investigations. The main features of this pump are as follows: rotor diameter - 147.1 mm, rotor length - 150 mm, six-threaded rectangular grooves with width 22.55mm by depth 4mm, the groove-head (vane) width - 10mm, the clearance between rotor and external cylinder - 0.45mm. From these data the value of angle between the direction of grooves and the pump axis may be deduced - 65 degrees.

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In order to check the accuracy of Kanki's model in the free molecular limit the simulations were also performed for plane representation of pump tract geometry, i. e. for unrolled cylinder surface on the plate. The region of simulation in this case is of parallelogram shape.

RESULTS AND DISCUSSION

In the experiments [1] the rotational speed N of the rotor varied in the range of 100 to 400 rps. The tested gases were Air, Ar, He and H_2. For Air the results of terminal vacuum p_1 are obtained for the values of back pressure p_2 from 1 to 0.001 torr. For the other gases the dependencies of attainable pressure (p_1) from gas flow rate G for three values of p_2 (1, 0.5 and 0.1 torr) and four values of N (100, 200, 300 and 400 rps) are reported.

The dependencies of compression ($p_2 / p_1 = K_1 / K_2$) from N for Air are presented in Fig. 1. Significant difference between the results for real geometry (curve 1) and plane geometry (curve2) both obtained for diffuse reflected solid surfaces ($\sigma = 1$) is caused by known peculiarity of transmission probability of plane channel – high contribution of molecules, that crossed the channel without collisions with surfaces. This effect is mainly pronounced for K_2 – for N = 400 rps the value of K_2 for plane geometry is about order of magnitude higher than that for real geometry. The results of Ref. [1] for $p_2 = 0.001$ torr are show by curves 3 (theory) and 4 (experiment).

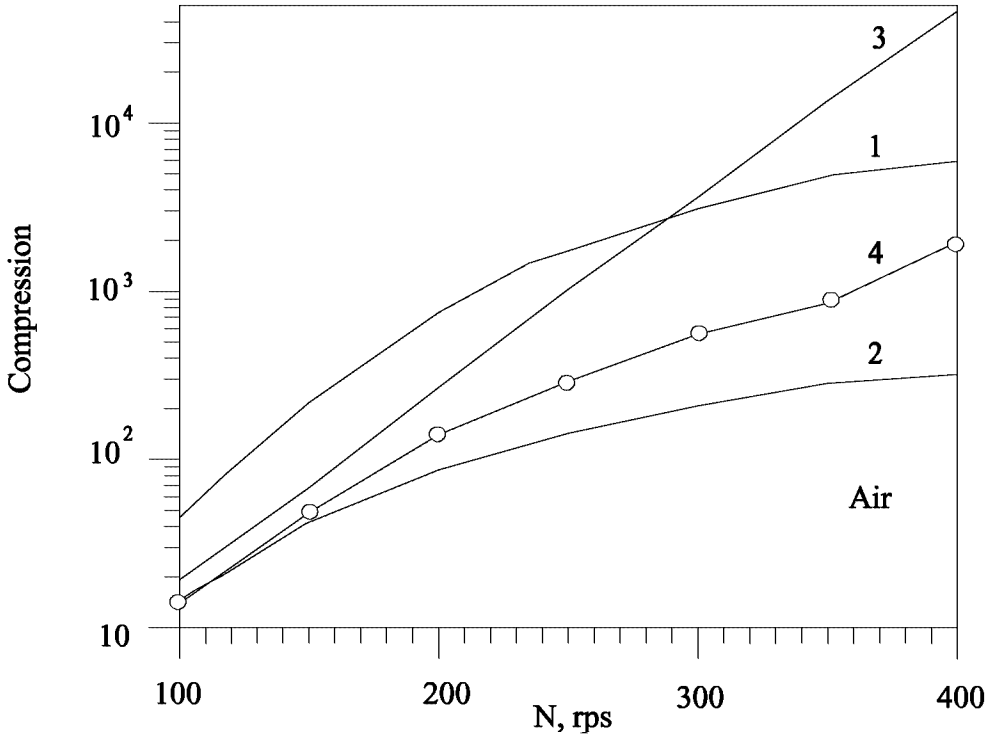

FIGURE 1. Compression as a function of rotational speed of the rotor.

For $p_2 = 0.001$ torr the flow in the pump is free molecular with high accuracy. Therefore, significant difference between curves 3 and 2 (more than two orders of magnitude at N = 400 rps) indicates about poor description of the free molecular flow in the plane geometry of the pump by the Kanki's model.

The shape of curves 1 and 4 is similar, though experimental results are systematically lower than theoretical ones. The reasons for this difference are not clear. One possible reason may be connected with the difficulties of exact measuring of low terminal pressure.

The dependencies of attainable pressure p_1 from G for H_2, N = 400 rps and $p_2 = 0.1$ torr are presented in Fig. 2. The notation of curves is the same as in Fig. 1. As can be seen from these data the exact theory for real geometry (curve 1) provides good description of experimental results (curve 4). As in Fig. 1 significant difference between the Kanki's model (curve 3) and exact theory for plane geometry (curve 2) takes place.

Similar situation takes place for other gases and values of N.

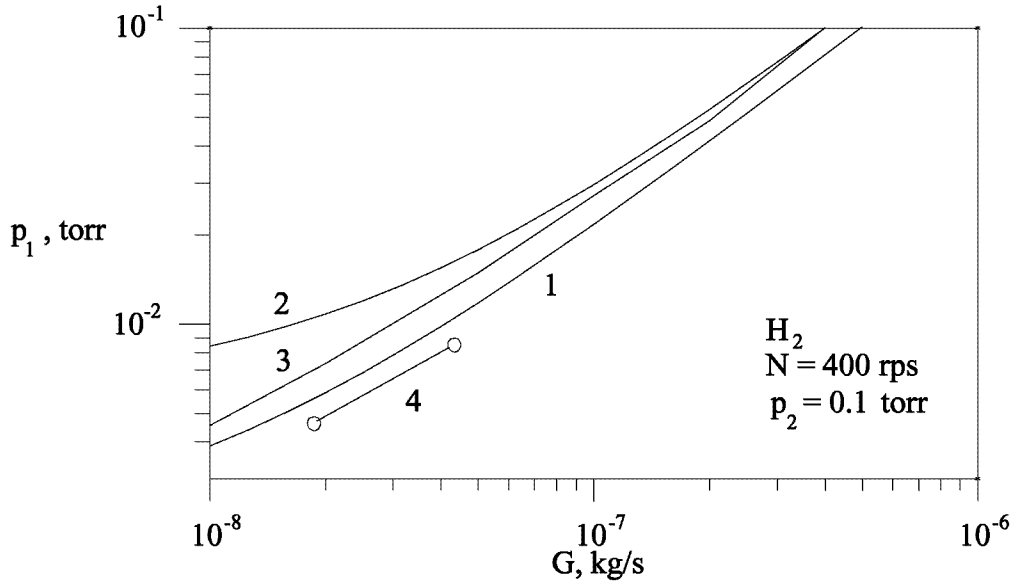

FIGURE 2. The dependence of attainable pressure from the gas flow rate.

A good description of low-pressure experimental results by Kanki's model is, therefore, the result of opposite effect of two factors:

a) Significant difference between the free molecular flow in the real cylindrical geometry and in its plane representation.
b) Poor description of the flow in the plane geometry.

Based on the results of free molecular flow simulation nothing can be said about applicability of the Kanki's model for the description of the flow in the pump at the conditions when the collisions between molecules became significant. Nevertheless, care should be taken while applying this model for the purposes of optimizing the real device having in mind its shortcoming for one of the important limiting case.

CONCLUSION

1. The numerical algorithm for simulation the free molecular flow in the Holweck pump based on test particle Monte Carlo method is developed. The results obtained by this method for real cylindrical geometry of the pump taking into account the rotation of the rotor with multi-grooved channels are in good agreement with measured results [1] for low pressure conditions. The developed algorithm in slightly modified form may also be used for simulation the flow in the inlet stages of turbomolecular pump.
2. The Kanki's model for the gas flow in the Holweck pump does not provide the correct description of the flow in the free molecular limit.

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